TECHNICAL REPORT

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ENGINEERING RESEARCH PROTOTYPE DISTRIBUTION SYSTEMS FOR THERMALIBRIUM CLOTHING

by

R. W. Austin, W. C. Hass

and

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Mine Safety Appliances Company

Pittsburgh, Pa.

Contract No. DA19-129-AMC-118 N

October 1967

Clothing and Organic Materials Laboratory

C&OM-37

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Clothing and Organic Materials Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

This report was prepared by the Mine Safety Appliances Company, Pittsburgh, Pennsylvania on Contract No. DA-19-129-AMC-118(N). The object of this contract was the development of an air distribution garment, in accordance with Government-furnished concepts and requirements, capable of fabrication on a practical production basis.

The object was accomplished in a two-phase program. The initial phase, Work Cycle I, July 5, 1963 - March 31, 1964, consisted of material optimization, design of a valving system, development of sizing patterns, development of fabrication techniques, and fabrication of two complete prototypes. The prototypes and all patterns were submitted to the U. S. Army Natick Laboratories at the completion of the first cycle.

The second phase, Work Cycle II, October 26, 1966 to April 26, 1967, consisted of pattern modifications, based on specified design changes by the Natick Laboratories, and fabrication of 34 complete garments on a modified production basis. The 34 garments and modified patterns were submitted to the U. S. Army Natick Laboratories.

The individual work cycles are covered in detail as Part I and Part II of this report.

The work was administered under the direction of the Advanced Projects Division, Clothing and Organic Materials Laboratory, U. S. Army Natick Laboratories, Natick, Mass., with Mr. Vincent Iacono, Jr. as project monitor.

S. J. KENNEDY
Director
Clothing and Organic Materials Laboratory

APPROVED:

DALE H. SIELING, Ph.D.
Scientific Director

W. M. MANTZ
Brigadier General, USA
Commanding

CONTENTS

CONTENTS (Cont'd.)

Page

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The results of material optimization, fabrication techniques and the fabrication of prototype air distribution systems for thermalibrium clothing are summarized. The engineering research effort was accomplished in two work phases. The initial phase was directed to the testing c materials, the development of fabrication techniques and the fabrication of two prototype systems for design verification testing at U. S. Army Natick Laboratories. The second phase of the program involved the modification of patterns, and the fabrication of 34 air distribution systems on a modified production basis. The counter-flow system of distributing ventilating and/or conditioned air for protective clothing can be manufactured under standard production methods, using commercially available materials.

ENGINEERING RESEARCH PROTOTYPE
DISTRIBUTION SYSTEMS FOR THERMALIBRIUM CLOTHING

I. CYCLE I

A. INTRODUCTION

Part I of this report covers the progress made in the first cycle of this contract. Materials for the garment were specified by the U. S. Army Natick Laboratories and the patterns for the outer garment were duplicated from ones loaned by the Natick Laboratories.

The work done on this cycle covers the original requirements and subsequent revisions. The original requirements were:

1. Compatibility with the concept for the U. S. Army experimental thermalibrium system.

2. Ability to be easily donned and doffed.

3. Comfort and flexibility during wear to insure minimum restriction of mobility.

4. Protection from CBR agents and high energy thermal pulses.

5. Positive seal closures and valves, protected against icing.

6. Maintenance of a slight positive pressure throughout the distribution system regardless of internal pressure fluctuations that may result from body motion during combat activities.

7. A comfortable, partial neck seal to reduce or prevent suit ventilating air from entering a headgear assembly.

8. Maximum flow resistance of the distribution garment to be less than 4 inches of water pressure at an air flow rate of 25 cfm.

9. Maximum total weight of assembly to be six pounds.

10. Design flexibility so that a minimum number of sizes will accommodate the 5th to 95th percentile range of body sizes for the U. S. Army population.

The revisions were:

1. The spacer layer, consisting of Trilock spacer, impermeable layer, and Trilock spacer, is to be considered as one layer only and each must be capable of removal. The underwear is to be considered as a separate unit not attached to the spacer layer.

2. The rough edges of the spacer material are to be taped at all points in contact with the body, using the outer garment material.

3. The collar for attaching the helmet is to be made an integral portion of the suit.

4. The spacer unit is to be sealed in the neck area to the outer layer.

5. The underwear portion is to be form-fitting and may be commercial material.

6. Inlet check valves are to close when the power unit is rendered inoperable.

7. The suit neck seal should be a positive seal if possible, but a semi-positive seal is acceptable.

8. The inner barrier material to be used in the production of the two suits will be a new material modified at areas of stress to allow for elongation.

9. With regard to exhalation valves, any size exhalation valves are permissible as long as the 1/2-inch water pressure can be maintained and the suit can dump 22 CFM.

10. The inner barrier material can be cut back as much as 4 inches shorter than the spacer material in the leg and arm sections. The spacer material can be shortened at least 1 inch in the sleeve and leg sections.

B. DISCUSSION OF WORK

1. Outer Garment Patterns. Initially, a suit was made from a cotton cloth, using Government-furnished patterns to become familiar with the fit of the patterns, the size of the suit, the method of assembly, and the possibility of envisioning problem areas. The finished suit indicated well-thought-out and designed patterns to produce a form-fit suit. Changes were required in the neck area for the attachment of a neck seal since the configuration was entirely different than the design originally developed with this suit. There was also a design change in the upper zipper area for the same reasons.

Sizing of the suit, as far as circumferential measurements were concerned, seemed to be adequate for a large size range fit, provided there was sufficient elongation in all the layers of materials. There did not appear to be an allowance for any great variation in height, leg or arm length. It was proposed that the cuff length of the ankle and wrist be extended approximately 1-1/2 inches to provide more adaptability to variances of body parts. On short legs or arms, the extended cuff can be turned back on itself, thus effectively shortening the length of the sleeve or leg.

2. Outer Material. The neoprene-coated nylon knit outer garment material was the first material received. Examination of this material indicated studies should be made regarding elongation versus load and methods of seaming or fastening the material.

Because the greatest variation in body measurements is the circumference measurements, elongation studies were conducted on strips cut from the width and length, as well as in the bias of the roll, to determine the direction of greatest stretch. A coating on a cloth material restricts the material from draping when cut on the bias and, without the draping effect, it is more practical to cut the material so that the greatest elongation occurs where the greatest stretch will take place. Elongation measurements were made using 2 inch wide strips and measuring the elongation over a marked 5 inch length at one pound increments of static loading. The elongation in inches was then converted to percent, and percent elongation versus loading curves were drawn. These curves (Figure 1) can be used to determine the load exerted on various parts of the body when the particular section is stretched to fit a larger size. For example: If the calf section is designed to give a close fit for the 5th percentile, what pressure will be exerted upon the calf of a person with a calf measurement of the 95th percentile? According to WADC Technical Report 52-321[1], the circumference of the calf for the 5th percentile is 12.9 inches and for the 95th percentile 16.0 inches. The calf section will then have to stretch 3.1 inches or 24.03 percent. Referring to Figure 1, there will be a load of 1.8 pounds exerted if the material is cut so the length of the roll encases the calf and only 1.2 pounds exerted if the material is cut so the width of the roll encases the calf.

Joining this outer material to itself by seams presents two major problems: (1) a strong seam which will withstand great stress and stretch, and (2) a seam which will not leak. Any sewing of seams must be followed by a sealant to close holes caused by the needle. Several type stitches, such as straight 301, straight 401, and zigzag 301, were tried. The straight stitch broke easily on any loading lengthwise or across the stitch. The zigzag stitch stretched with the material lengthwise and a little crosswise of the seam, showing great improvement over a straight stitch.

Cementing the seams without the sewing appears to be a better method. Several types of seams were made with adhesives, with and without stitching. These seams were placed in a cold chamber for two hours at -40°F. and immediately upon removal were grasped firmly and given a quick, strong pull lengthwise and across the seam. Any damage was noted. The same samples were then placed in an oven for two hours at 140°F. and the same test conducted. From the results of these tests, a plain 1/2 inch lap cemented seam was proposed. See Table I for types of seams and results of tests.

---

1. WADC Technical Report 52-321
   Anthropometry of Flying
   Personnel - 1950
   by H.T.E. Hertzberg
   G. S. Daniels and E. Churchill
   Wright Patterson A. F. Base
   Sept. 1954

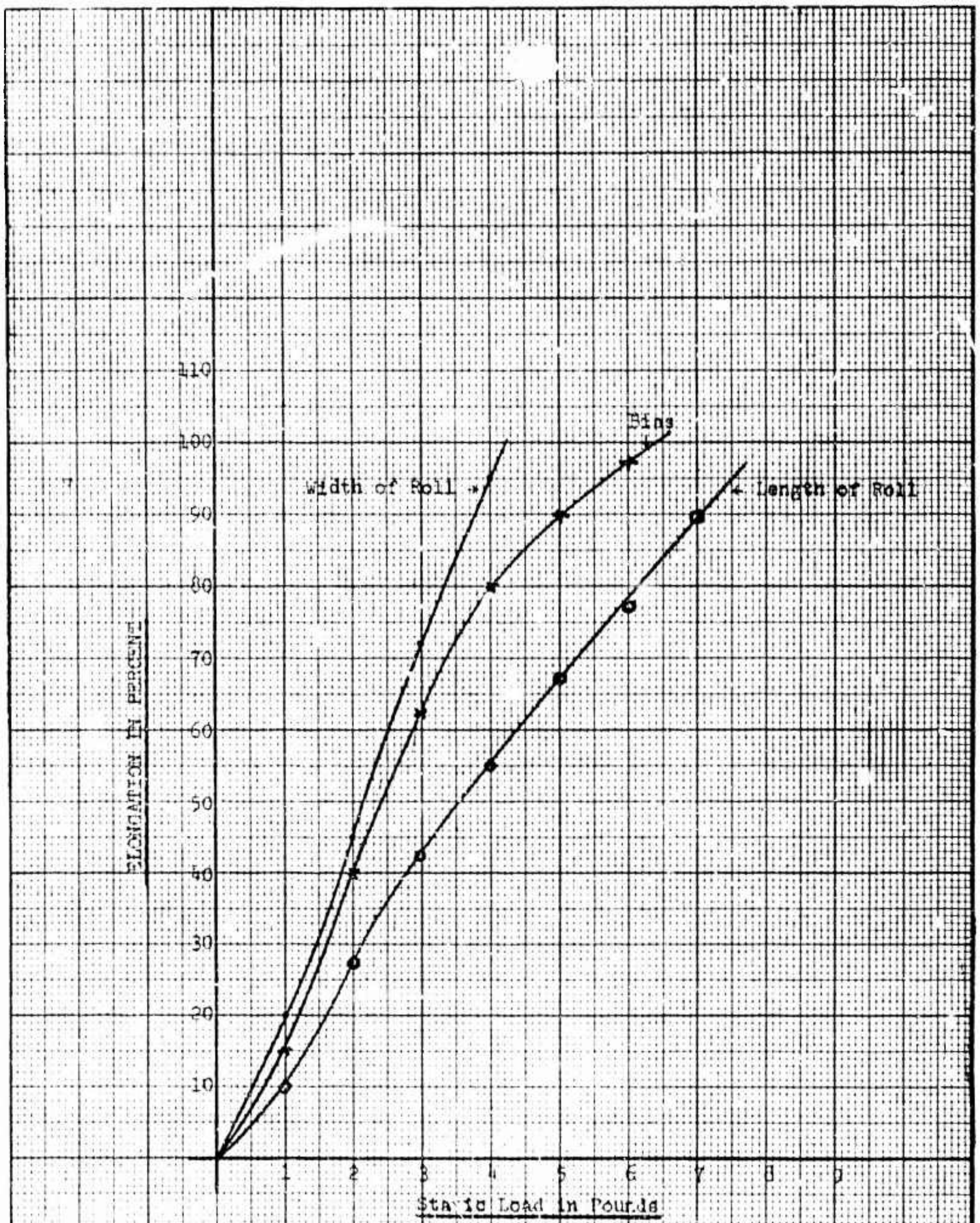
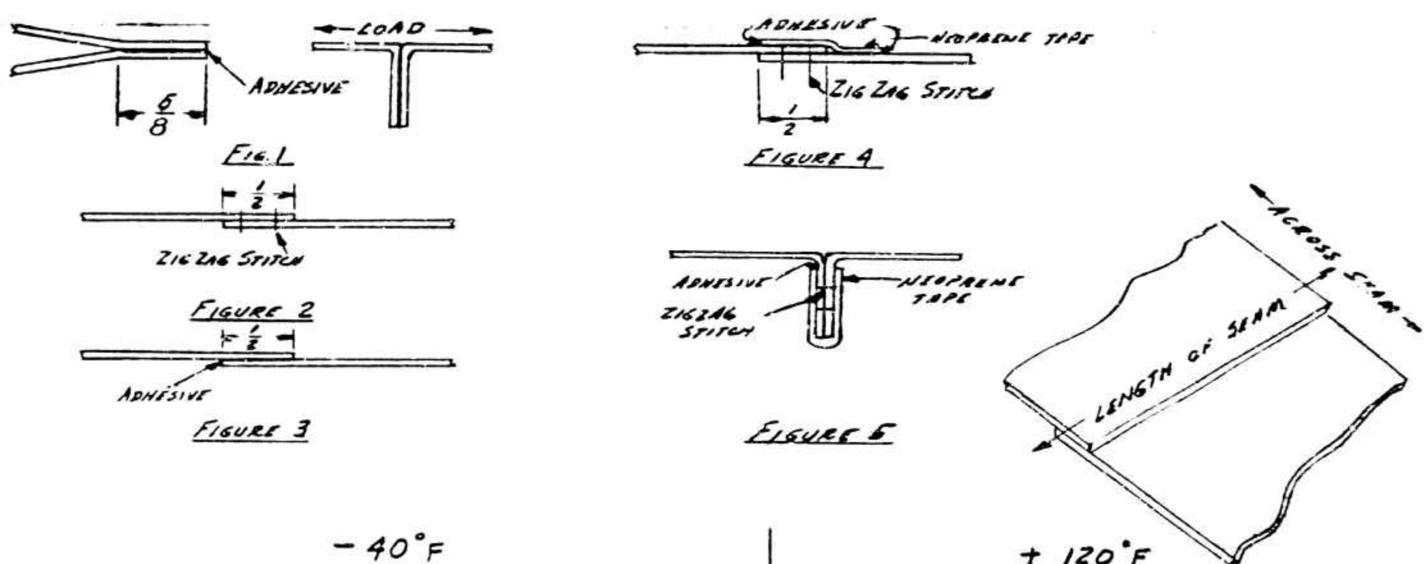


FIGURE 1. Elongation Vs. Load of 2/10 Nylon Knit, Coated With .010 Neoprene Rhee Industries

TABLE I



	−40°F		+120°F	
TYPE SEAM	ACROSS SEAM	LENGTH OF SEAM	ACROSS SEAM	LENGTH OF SEAM
FIGURE 1	ADHESIVE BOND FAILED			
FIGURE 2	NO APPARENT DAMAGE	NO APPARENT DAMAGE	NEEDLE HOLES TORE	NO DAMAGE
FIGURE 3	NO DAMAGE	NO DAMAGE	NO DAMAGE	NO DAMAGE
FIGURE 4	NO DAMAGE	NO DAMAGE	NEEDLE HOLES TORE	ONE STITCH BROKE
FIGURE 5	NO DAMAGE	NO DAMAGE	TWO STITCHES BROKE NEEDLE HOLES TORE	NO DAMAGE

Types of Seams

THERMALIZATION SUIT
CYCLE I

3. Spacer Material. The spacer material was tested for elongation, previously described, and the resulting curve is shown in Figure 2. This material should definitely be cut on the bias. The spacer material has a great tendency to fray at the edges, creating seaming problems. The following methods were investigated to prevent raveling:

a. Open flame.
b. Hot bar.
c. Serg stitch.
d. Bias tape.
e. Elastic tape.
f. Adhesive.
g. Electronically sealed vinyl.

Of these methods, the adhesive and electronic methods were satisfactory. The adhesive method was furnished initially because of the simple equipment necessary, a dipping tray. These samples were subjected to temperature flexure tests (2 hours at +140°F. and then 2 hours at -40°F.). After two hours at the high temperature, the edges were checked for tackiness by folding them 180° and pressing the edges against themselves. After the two hours at the low temperature, the samples were folded in the same manner to determine cracking or breaking. At the high temperature, the vinyl was soft, but neither the vinyl nor the adhesive was tacky. At the low temperature, the vinyl cracked, always in the area of the dark-colored threads.

With either the adhesive or vinyl edgings, a butt seam can be fabricated by a zigzag stitch, a binding tape sewn close to the edges of the spacer material, or elastic strips wide enough to sew substantially away from the butt seam edges. Both the zigzag stitch and the binding tape put all of the elongation stress on the spacer material, thus limiting the degree of stretch to the characteristics of the spacer material only. A wide elastic strap will not only allow the spacer material to elongate but will augment the total elongation by its own elongation characteristics.

Figure 3 shows a double and single wide elastic butt seam illustrating a load and no-load condition. With the double elastic there is little elongation present in the elastic due to the double load necessary to produce the same percentage of elongation as a single layer. Thus, in this structure the greatest elongation takes place in the spacer material. With the single elastic, the elongation at the seam is much greater and the spacer and elastic elongate together. Several elastic-type materials (girdle elastic) were investigated with the result that Lycra No. 4605, made by the J. W. Wood Company, is to be initially utilized. The elongation curves for this material are shown in Figure 4. While the greatest elongation of the Lycra material is on the bias, there is sufficient elongation across the width, in combination with the elongation of the spacer material, to provide the elongation needed. This allows the Lycra material to be cut lengthwise of the roll, making it more efficient for cutting and handling, and reducing scrap loss.

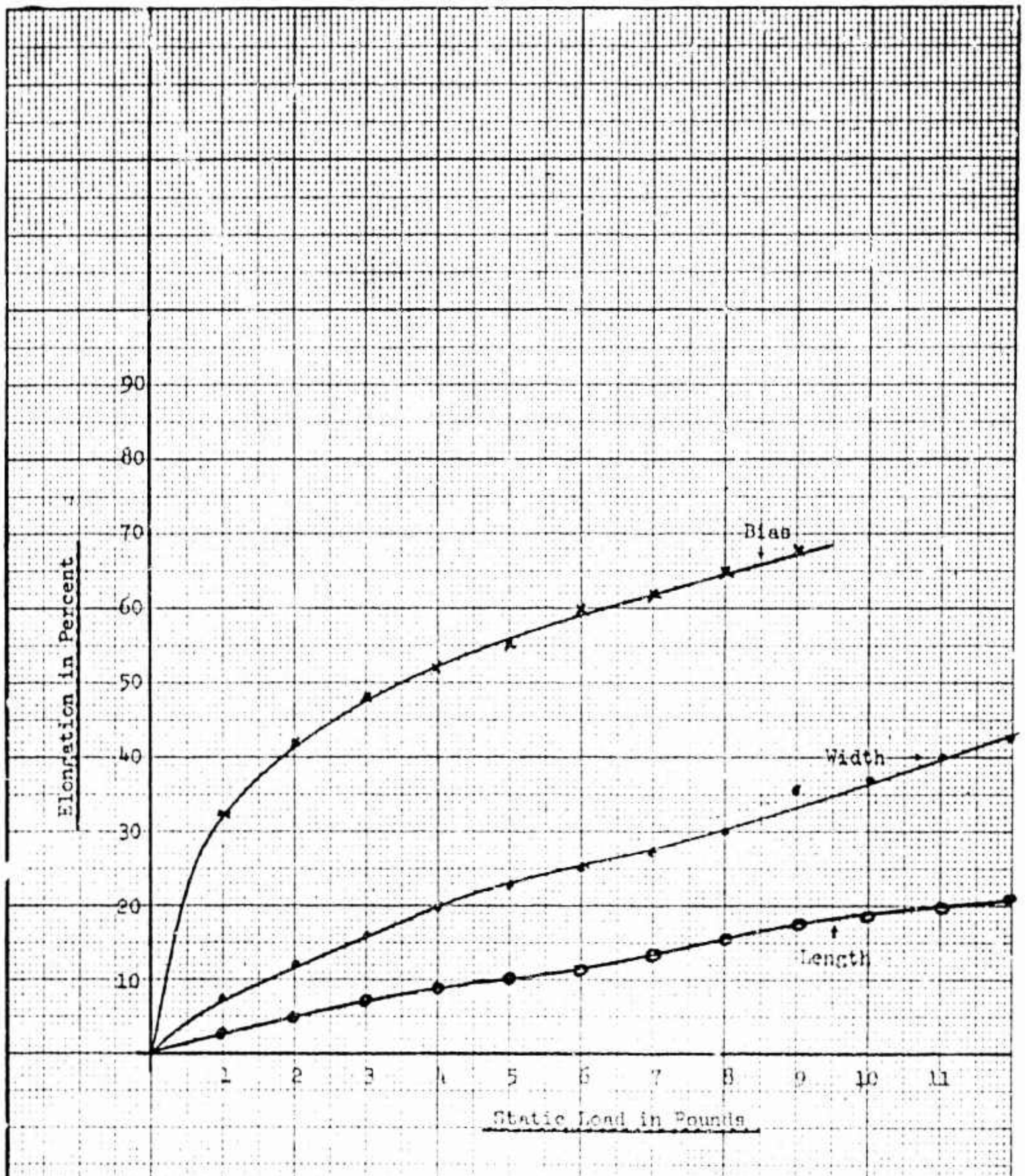


FIGURE 2. Elongation Vs. Load For Trilock
Base Spacer
U. S. Rubber Co.

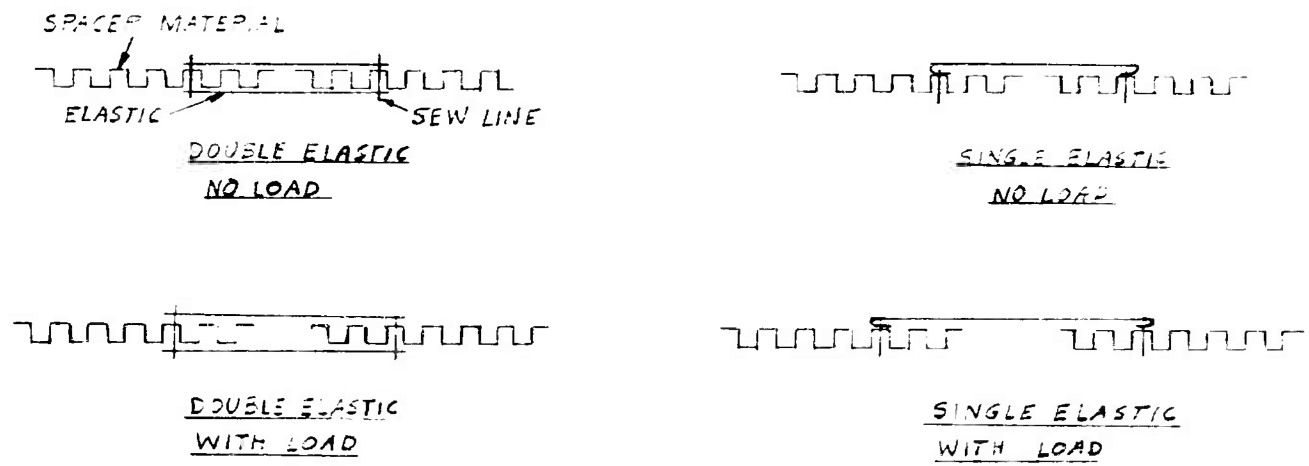


FIGURE 3. Elastic Seams

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THERMALIBRIUM SUIT
CYCLE 1 11-21-63

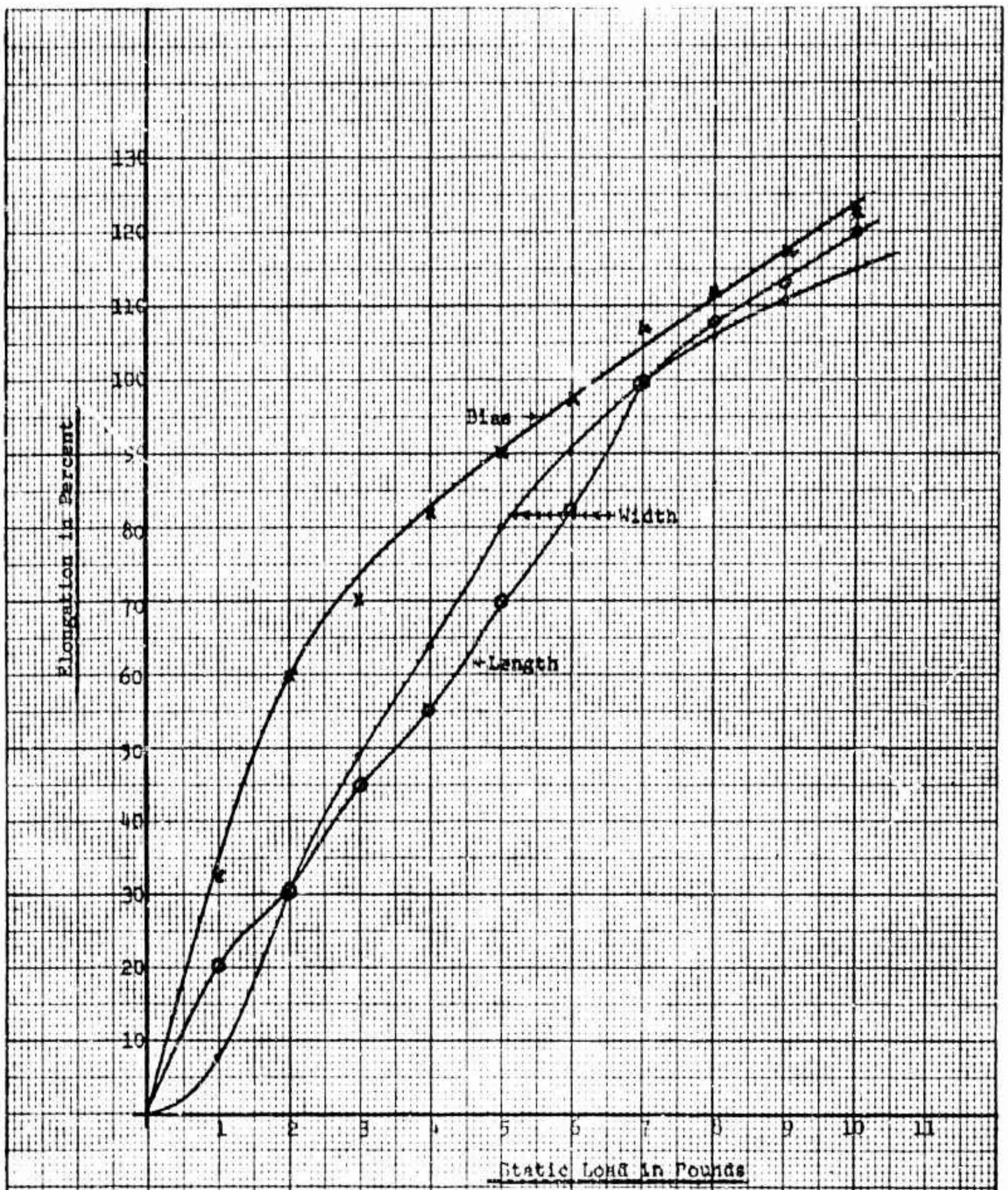


FIGURE 4. Elongation Vs. Load of
Lycra No. 4605
J. W. Woods Co.

4. Barrier Material. The barrier material, an unsupported white neoprene 0 mil. in thickness, definitely cannot be stitched. The material is very notch-sensitive and the smallest notch propagates a tear under loading. This material can be cemented successfully into a strong lap seam, but the tendency of the material to curl when adhesive is applied makes the cemented seam very difficult to produce. The elongation versus load curves are shown in Figure 5.

Because of the low tear strength of the unsupported neoprene, it was decided to replace this material by Hodgeman Rubber Company's TD-3780 Style N160DC double-coated polyurethane nylon cloth. This material has a higher tear strength as well as an aluminized coating on one side under the polyurethane coating. The material can be sewn, giving strong seams, but cemented seams are not considered satisfactory. The weight is 3 ounces per square yard (much lighter than the 10 ounce per square yard of the neoprene film). The elongation on the length and width is very low but is considerably higher on the bias (Figure 6). This material should be cut on the bias. The necessary elongation in the fabricated barrier can be supplied by joining the various patterns at the seams (Figures 7 and 8), using the neoprene-coated nylon knit outer garment material. This will supply the necessary elongation for circumference and lengthwise stretch, and panels of the same material added into cutouts at the joint areas will provide sufficient elongation for the linear distance changes over the body joints.

5. Inner Garment Material. The underwear, made from a cotton knit tubing material, must be highly moisture-absorbent. Static absorption tests following the procedures of ASTM D583-54 1955 Standards were run on two cotton knit materials and two commercially made sets of underwear. One set of commercial underwear was a cotton thermal of raschell knit and the other a plain cotton knit. The two cotton knit materials were Ml-Jan fabrics, identified as stretch cotton tubing Style 2325CM and 30 c/p plain jersey cotton yarn knit tubing. Results of these tests are shown in Table II.

Elongation tests, described previously, were run on the two Ml-Jan materials. The elongation curves for these materials are shown in Figures 9 and 10. The Ml-Jan 2325CM material must be serg-stitched on all edges and reinforced in critical areas due to poor tear strength. This material may not stand up under hard wear. Although the Ml-Jan 30 c/p plain jersey cotton is the lightest in weight, the Ml-Jan stretch cotton tubing Style 2325CM has the best absorption qualities and the underwear furnished with these suits was made from this material.

6. Inner Garment Patterns. The Natick Laboratories indicated that the spacer layer seams should be butt seams because of the bulk that a lap seam creates. Butt seams were constructed as shown in Figure 7 (Sketch 1) and assembled in a vest portion for fit. The edges of the spacer material tended to lap each other, causing bulk in the seam areas. The excess spacer material between the sew lines of the Lycra was removed, thus removing

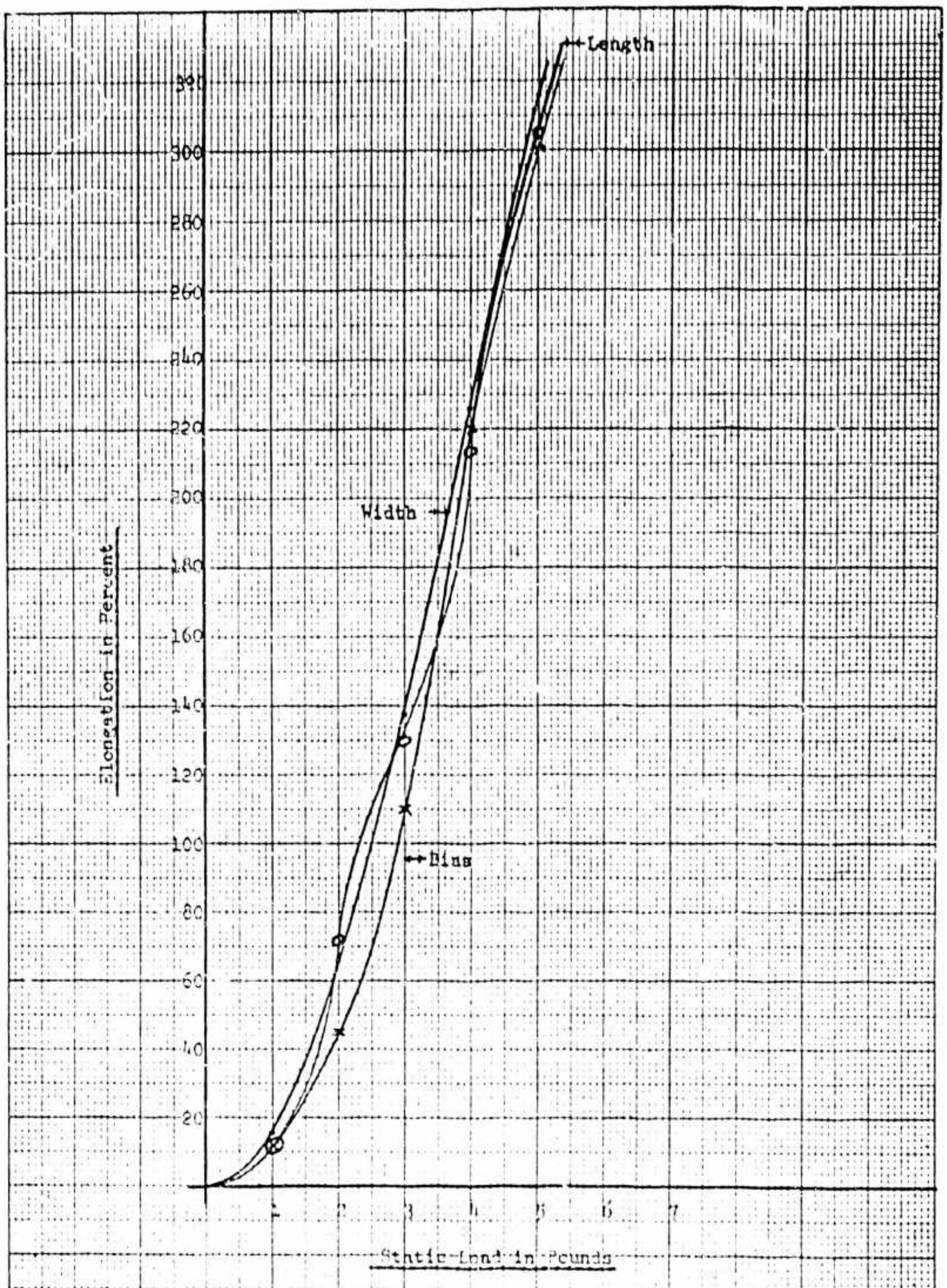


FIGURE 5. Elongation Vs. Load of .010 Unsupported White Neoprene Rheo Industries

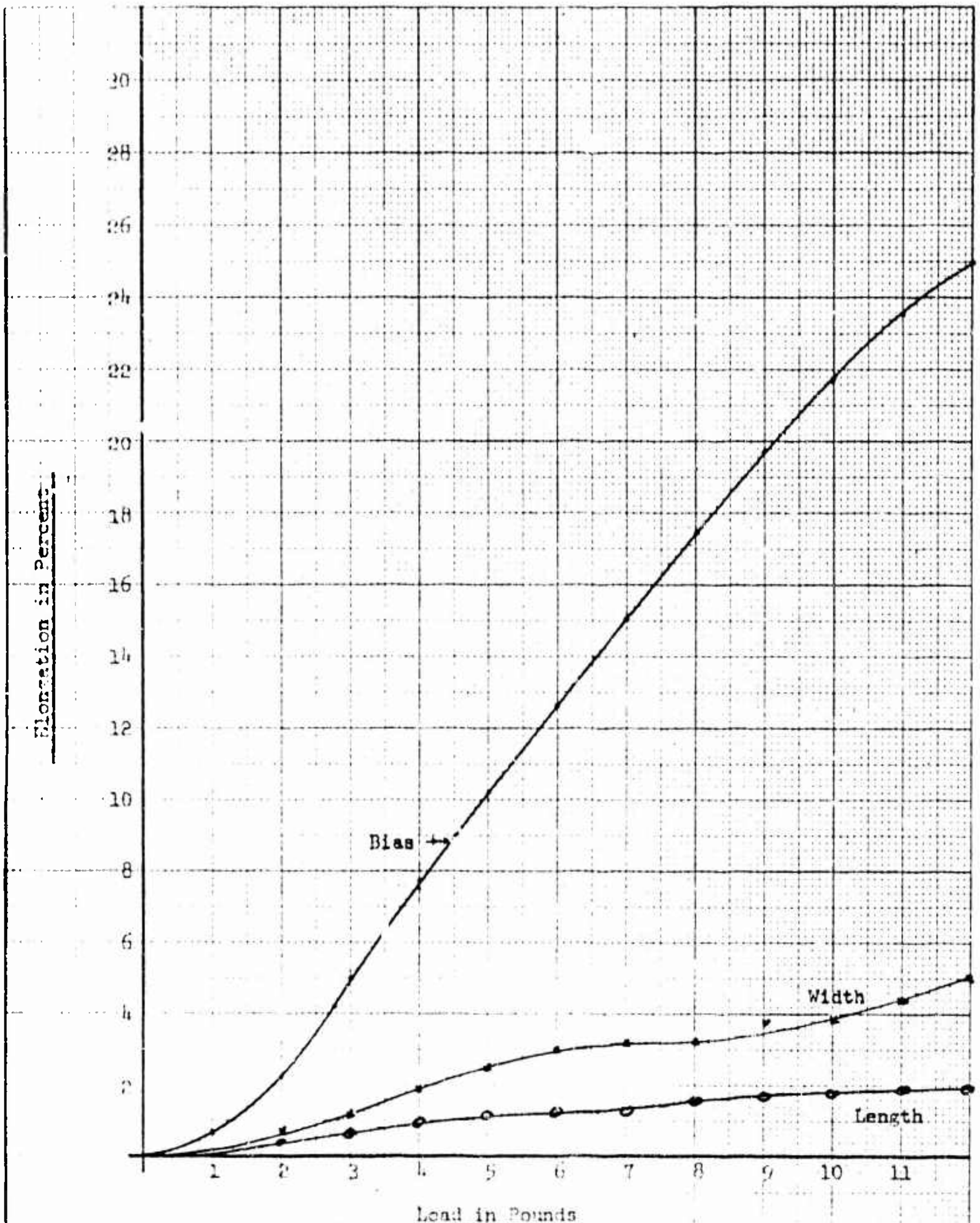
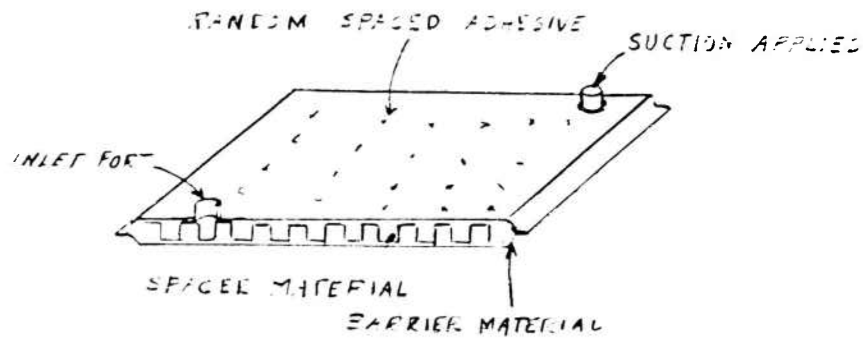
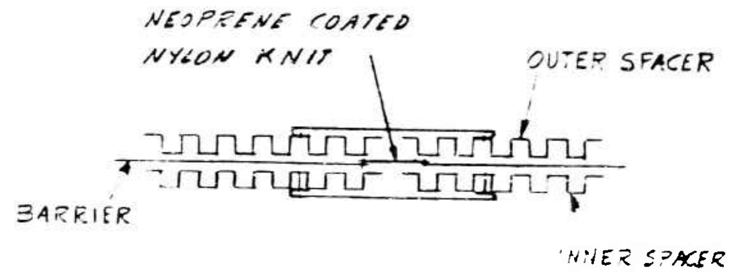


FIGURE 6. Elongation Vs. Load of
Polyurethane Coated Nylon
Hodgeman Rubber Co.
TDA-3780, Style N 160-DC



SKETCH 2



SKETCH 1

FIGURE 7. Butt Seams

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CYCLE I 4-3-64 HA

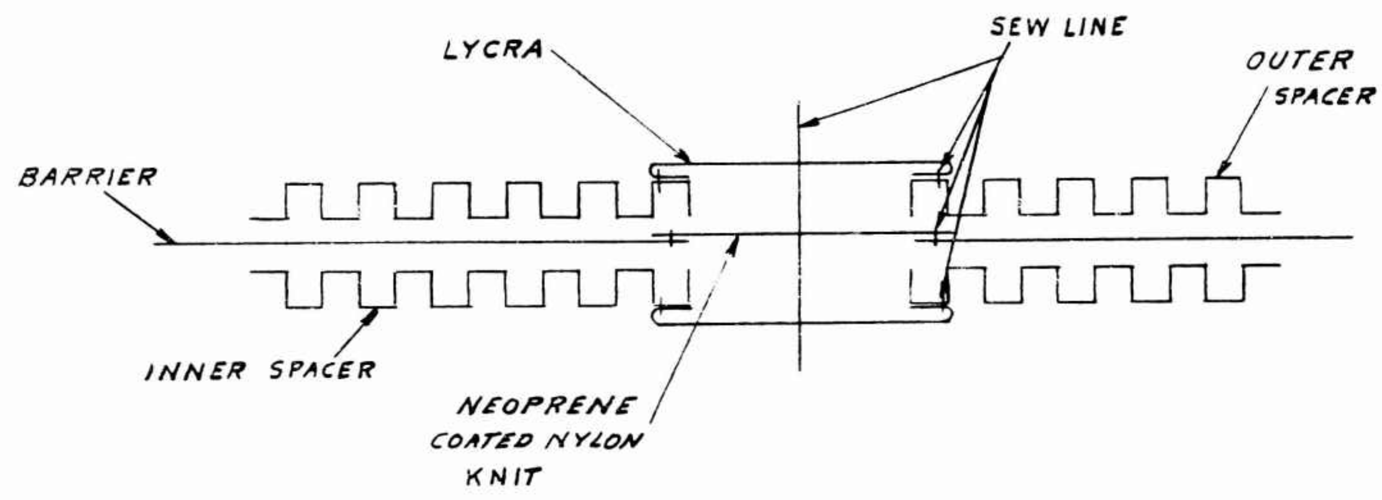


FIGURE 8. Barrier and Spacer Positioning

AC 829
THERMALIBRIUM SUIT
CYCLE ! 4-3-64 HM

TABLE II

STATIC ABSORPTION TESTS

ASTM D583-54
1955 STDS.

MATERIAL	DRY WEIGHT OZ./SQ. YD	PERCENT WT. GAIN 24 HOURS @75% R.H.	PERCENT WT. GAIN 20 Min. SOAK 10 Min. DRAIN	PERCENT WT. GAIN AFTER 35 lb. ROLLER
HANES COTTON THERMAL UNDERWEAR (RASCHELL KNIT) COMMERCIAL	7.71	8.4	540.7	117
WEST COTTON UNDEDWEAR (TUBULAR KNIT) COMMERCIAL	6.98	8.0	407.7	84.5
MI-JAN STRETCH COTTON KNIT TUBING MATERIAL STYLE 2325 CM PC8182 B	4.26	11.5	307	60.6
MI-JAN 30/CP PLAIN JERSEY COTTON YARN TUBULAR KNIT	3.33	5.8	43.6	30.5

THERMALIBRIUM SUIT
CYCLE 1 HM 4-2-64
AC823

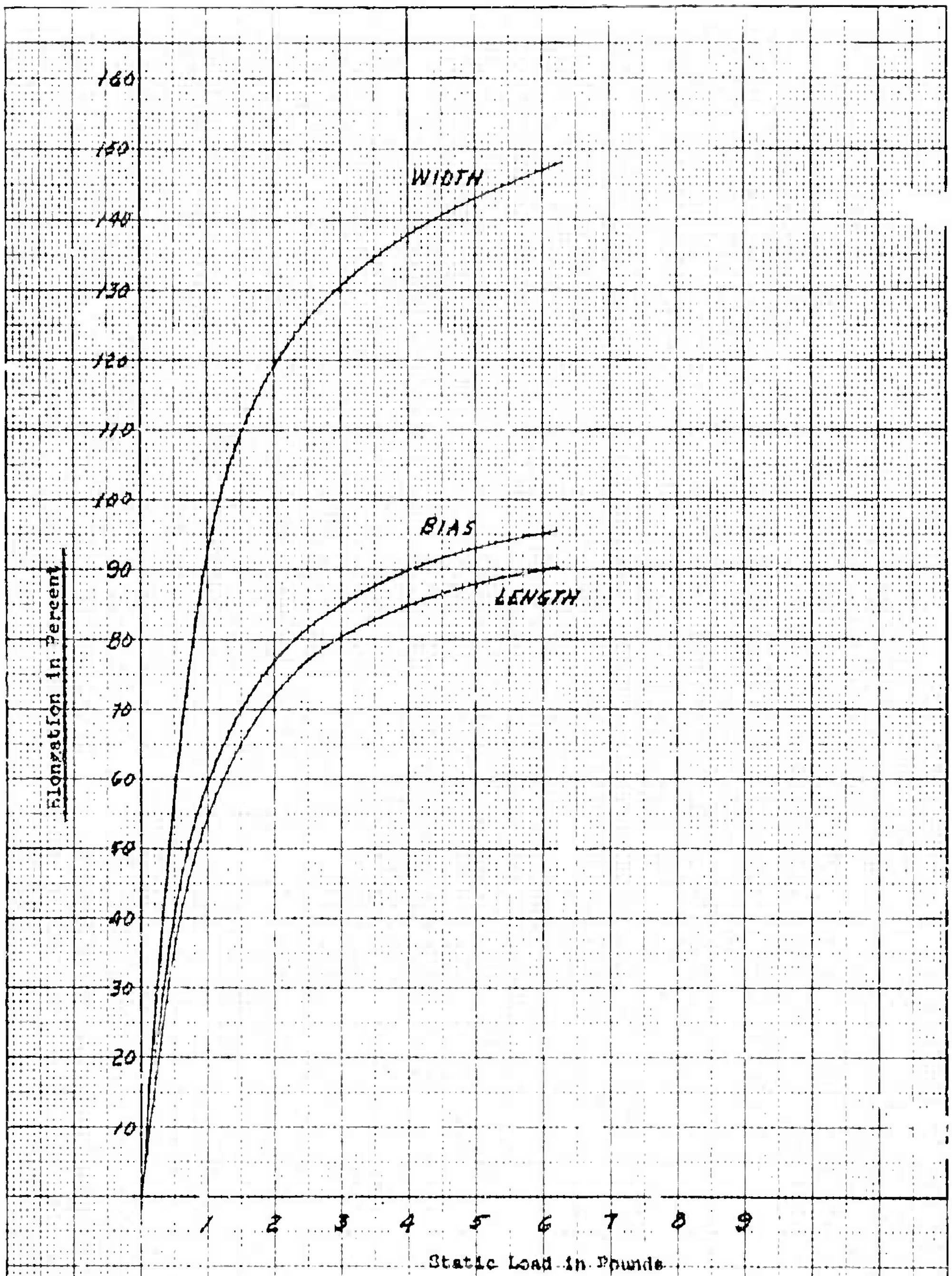


FIGURE 9. Elongation Vs. Load of Stretch Cotton Tubing Style 2325 CM Mi-Jan Fabrics Inc.

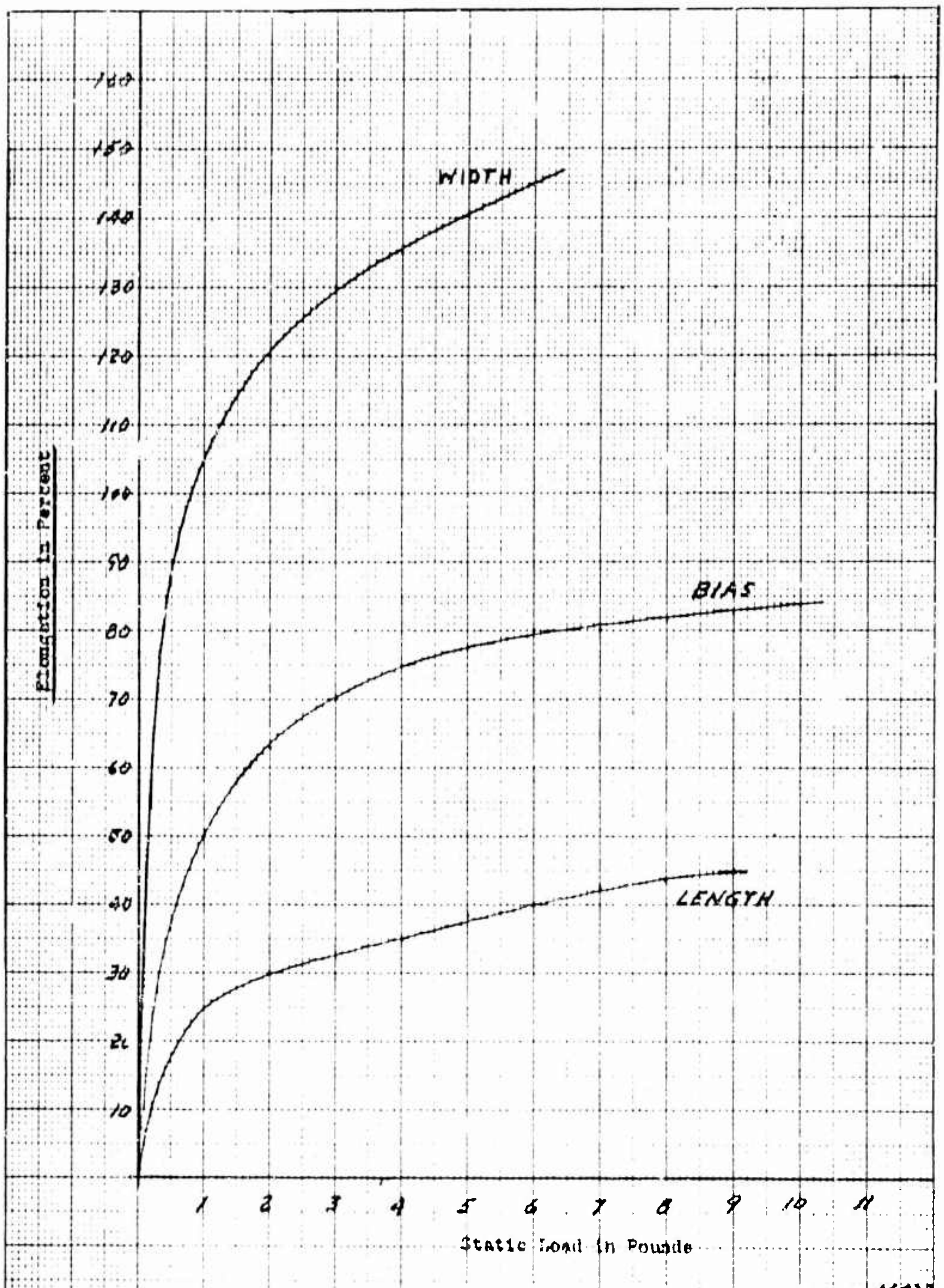


FIGURE 10. Elongation Vs. Load of
30 C/P Plain Jersey
Cotton Yarn Knit Tubing
Mi-Jan Fabrics, Inc.

the bulk and reducing the weight (Figure 8). Using a 3-inch-wide strip of Lycra and allowing for the 1/2-inch wide seams on the outer garment, and a half inch on the spacer material, the outer spacer patterns were cut approximately 1-1/2 inches shorter than the outer garment patterns on all of the seams. The inner spacer, using the same type of assembly, was cut 1/4 inch shorter than the outer spacer on all of the seams.

The barrier patterns were cut 2 inches shorter on all seams than the outer garment patterns by using a 3-inch-wide strip of neoprene-coated nylon knit material in the seams and allowing a 1/2-inch-wide sew line.

The length of the spacer sleeve patterns was cut 6 inches shorter and the leg patterns 7 inches shorter than the outer garment patterns, and the barrier patterns were cut 2 inches shorter in the sleeve and 3 inches shorter in the leg than the spacer patterns.

Areas were cut out of the spacer patterns in back of the knee, in front of the elbow, in the groin section, and under the arms to remove bulk and restrictions to leg and arm movements. The cutouts in the joint areas of the inner spacer were filled with webs of Lycra material to prevent the arms or legs of a person becoming entagled during donning.

7. Positioning. Locating and positioning the various layers with respect to each other so that they retain their relative positions, yet can flex and move independently, is rather complex. First, considerations were given to the sandwich structure of the barrier and spacer layers. Adhesives were considered, but it was felt that adhesives would have a tendency to increase the internal resistance. Panels were made up, 12 inches square, using adhesives to bond the barrier material to the spacer, and resistance measurements were made and compared to a similar panel constructed without adhesives (Figure 7, Sketch 2). As expected, there was considerable increase in resistance in the panel using adhesives (Figure 11).

The sandwich structure was then sewn together using a zigzag stitch and running the sew line parallel to the length of the seam and in the center of the elastic materials used in the seams (Figure 8). Where the sewing machine could not reach (in the arms and legs), the fastening was made by hand-tacking at spaced intervals. The use of the zigzag stitch in the center of the seam allows the sandwich structure to stretch both in circumference and lengthwise without undue restrictions.

The spacer layers were fastened together at the ends of the legs and sleeves using a binding tape cut from the outer garment material. This shields the wearer from any abrasions from the rough edges of the spacer material as well as protecting the outer garment against puncture. The edges along the zipper and neck were treated in like manner, except the barrier is also joined as part of the sandwich. This prevents the air from

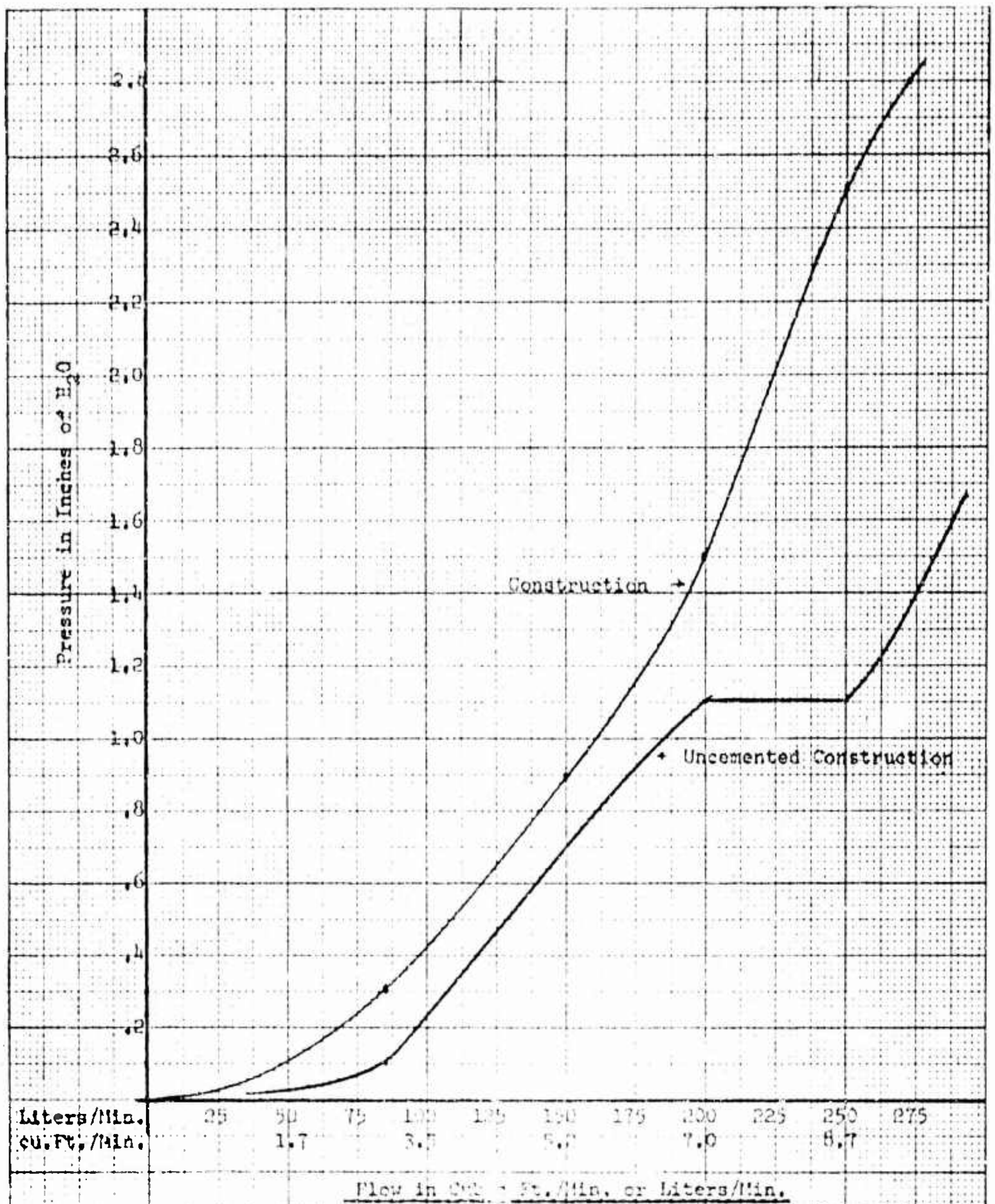


FIGURE 11. Pressure Vs. Flow
Barrier and Spacer Laminate

short-circuiting from the inner spacer to the outer spacer.

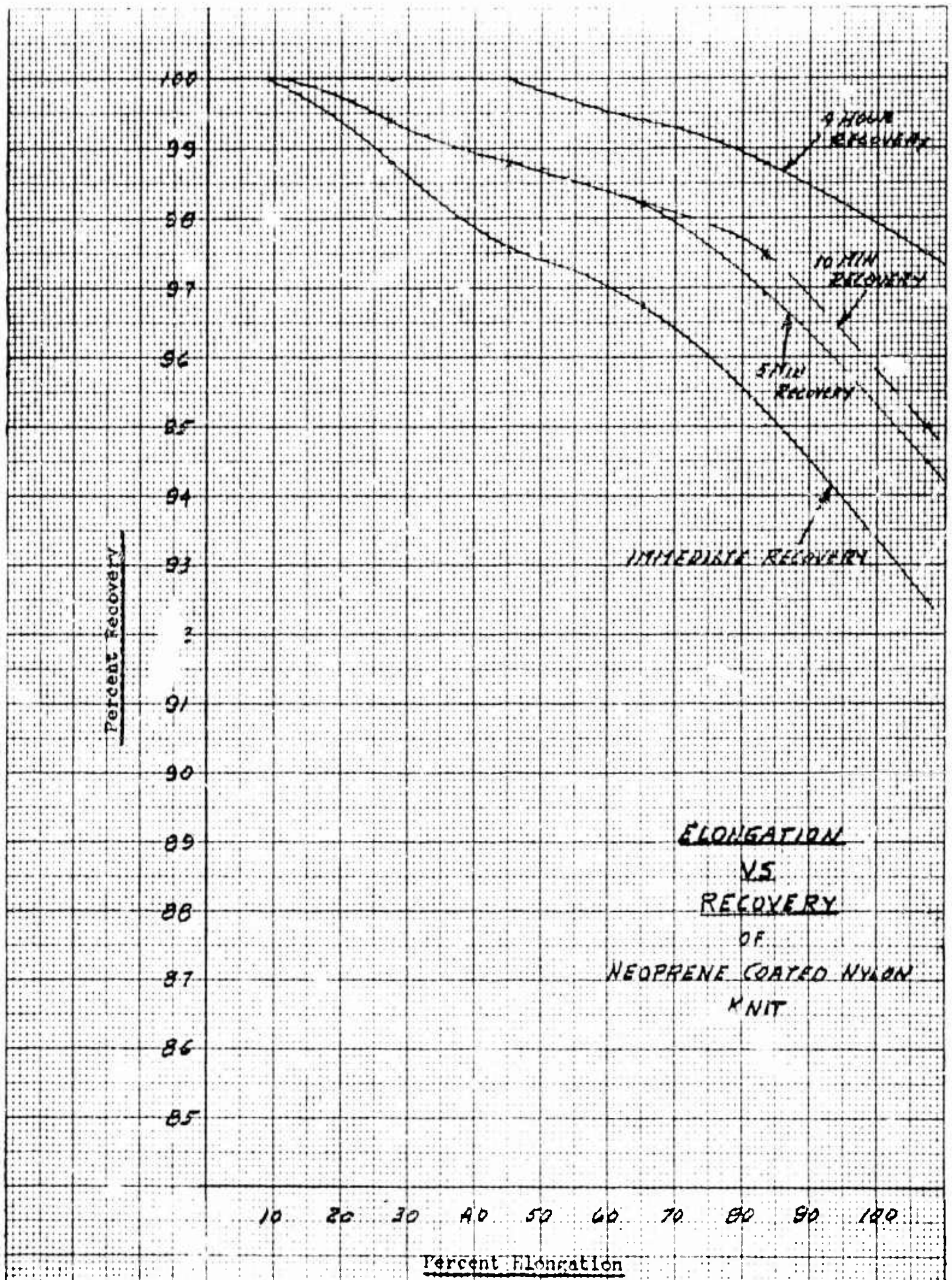
Positioning the spacer barrier assembly to the outer garment was accomplished by the use of snap-fasteners. Two fasteners, located at the end of each arm and leg of the outer garment, engage mating parts at the ends of the arms and legs of the spacer barrier assembly. These fasteners keep the inner garment from creeping up or twisting out of position during donning, doffing and while in use. The layers were also positioned along the length of the zipper at the front and around the neck area by snap fasteners. The inlet ports position the back area. If necessary, additional snap fasteners can be added along the length of the arms and legs. The snap fasteners, located in the zipper neck area, were embedded in a polyurethane foam strip fastened along this edge of the spacer barrier assembly. This foam strip seals the space between the outer garment and the spacer barrier garment and prevents the air flow from short-circuiting around the edge.

It was decided that the underwear be considered an entirely separate garment and be independent of the rest of the suit as far as attaching was concerned. From the standpoint of cleanliness, this was considered a desirable approach and would also permit changing the type of underwear, i.e., winter or summer.

8. Neck Seal. The neck seal can be approached in two ways: (1) Using a continuous ring effect which must be pulled on over the head or (2) an open collar type which must be snugged tight and closed around the neck. The continuous ring type has the advantage of being able to use a closed-end zipper and a more positive type of seal, but has the disadvantage of needing a material which can elongate at least 75% to go over the head and has 100% recovery to fit around the neck. The necessity of pulling on over the head makes it difficult to don and doff the suit. The open-collar type makes it much easier to get into and out of the suit, but it means the use of an open-end zipper which presents serious sealing problems and a less positive seal at the neck.

Because of the preference for a good neck seal, the continuous ring type was considered for use. The neoprene-coated nylon yard outer garment material has a high elongation under low load (Figure 1) and excellent recovery characteristics (Figure 12). Using a neck seal circumference of 13 inches, there will be an elongation of 83.6% of the circumference when pulled over a size 7-5/8 head (head circumference 23-7/8 inches) with an immediate recovery of 95% (Figure 12).

A continuous ring neck seal was constructed and attached to an extended collar portion of the suit, raising the neck seal approximately 3 inches above the normal collar level. A closed-end zipper, starting at the crotch area and extending almost to the junction of the collar and the neck seal, places the top portion of the zipper sufficiently high for a man to pull the collar over his head. The suit was then filled with a 5%



AC 828
THERMALIBRIUM SUIT

FIGURE 12.

concentration of Freon and the neck area was probed for leakage. The leakage showed [illegible].5 parts per million except at the area where the material was lapped. At this point the leakage indication was off scale. Initial efforts to reduce the leakage at this offset were not successful, but no real problem is anticipated in correcting this leakage. A General Electric Halogen Leak Detector was used for these tests.

9. Inlet Valve. The two inlet valves were located kidney high, one on each side of the back, and are the same in principle as the inlet valve supplied on the headgear. The inlet opening is larger than that in the headgear to compensate for the higher rate of flow and the valve has been reduced in thickness to reduce bulkiness which might cause pressure points on the back. A quarter turn releases the inlet tube and the inlet opening is then shut by a spring-loaded valve (Figure 13).

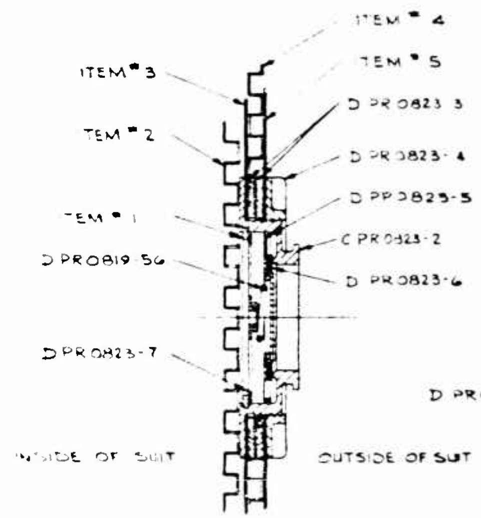
10. Exhaust Valve. The two exhaust valves, located in the chest area, one on each side, should be as flat and compact as possible to prevent pressure points and to reduce weight to a minimum. For this purpose, a check valve was designed consisting of a flat metal disc which was attached at its periphery to the outer garment by adhesive. There are two configurations which were considered with this design (Figure 14). A prototype assembly with a design I valve having a 1-1/4-inch-diameter orifice was tested (see page 27), and met the requirements. The suits supplied on this cycle were provided with the design I valve with a 1-1/4-inch diameter orifice.

It was found in testing the suit that the back pressure dropped when the exhaust valves were moved away from the chest. A circular pad, made from the spacer material, was added between the inside of the valve and the outer spacer to reduce the possibility of increasing the resistance due to a large-chested individual.

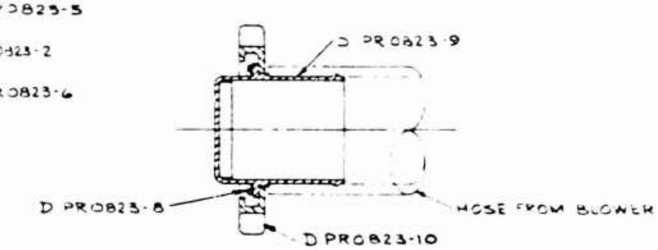
The plates furnished with these suits were made of 1/16-inch-thick aluminum, but could be made of almost any material.

11. Weight. The weight of the suit, less the underwear, is approximately 7-3/4 pounds. The weights of the component parts are:

	Weight in Oz.
Underwear made from Mk-Jan Style 2325CM Knit	10
Zipper - B. F. Goodrich Style 530 closed both ends 38" long	4
Inhalation valve - without hose connector (1)	3.75
Reinforcing gasket (1)	.22
Exhaust valve plate (1)	.55
Outer garment with valves and zipper	46.25
Spacer barrier assembly	77.25
20 sets snap fasteners	4.2
Polyurethane foam 3/[illegible]" thick x 1" wide x [illegible] long	.5



PARTS LIST			REVISIONS
PT. NO.	REQ'D.	DESCRIPTION	
PR 0823-2	1	BLOWER INLET VALVE	
PR 0823-3	2	VALVE GASKET	
PR 0823-4	1	VALVE RETAINER	
PR 0823-5	1	VALVE SEAL	
PR 0823-6	1	VALVE SEAL GASKET	
PR 0823-7	1	VALVE SEAL SPRING RETAINER	
PR 0819-56	1	INLET VALVE SEAL SPRING	
PR 0823-8	1	INSERT GASKET	
PR 0823-9	1	VALVE INSERT	
PR 0823-10	1	LOCK RING	
ITEM # 1	1	RETAINING RING [illegible] 5000-236 OR EQ.	
ITEM # 2	1	INNER SPACER	
ITEM # 3	1	BARRIER	
ITEM # 4	1	OUTER SPACER	
[illegible]	1	OUTER GARMENT	



MSA STANDARD SHOP PRACTICE APPLIES

MINE SAFETY APPLIANCES COMPANY PITTSBURGH, PA., U.S.A.	TOLERANCES UNLESS OTHERWISE SPECIFIED FRACTIONAL + - DECIMAL + - ANGULAR + -	FIGURE 13. Inlet Valve	DR. CHB 4-9-64 CHK'D JOB NO. AC-823 SCALE FULL	THERMALIBRIUM SUIT BLOWER INLET VALVE ASSY. PART NUMBER C PR0823-11
ALL MACHINED SURFACES ARE √ UNLESS OTHERWISE SPECIFIED	DO NOT SCALE DRAWING			

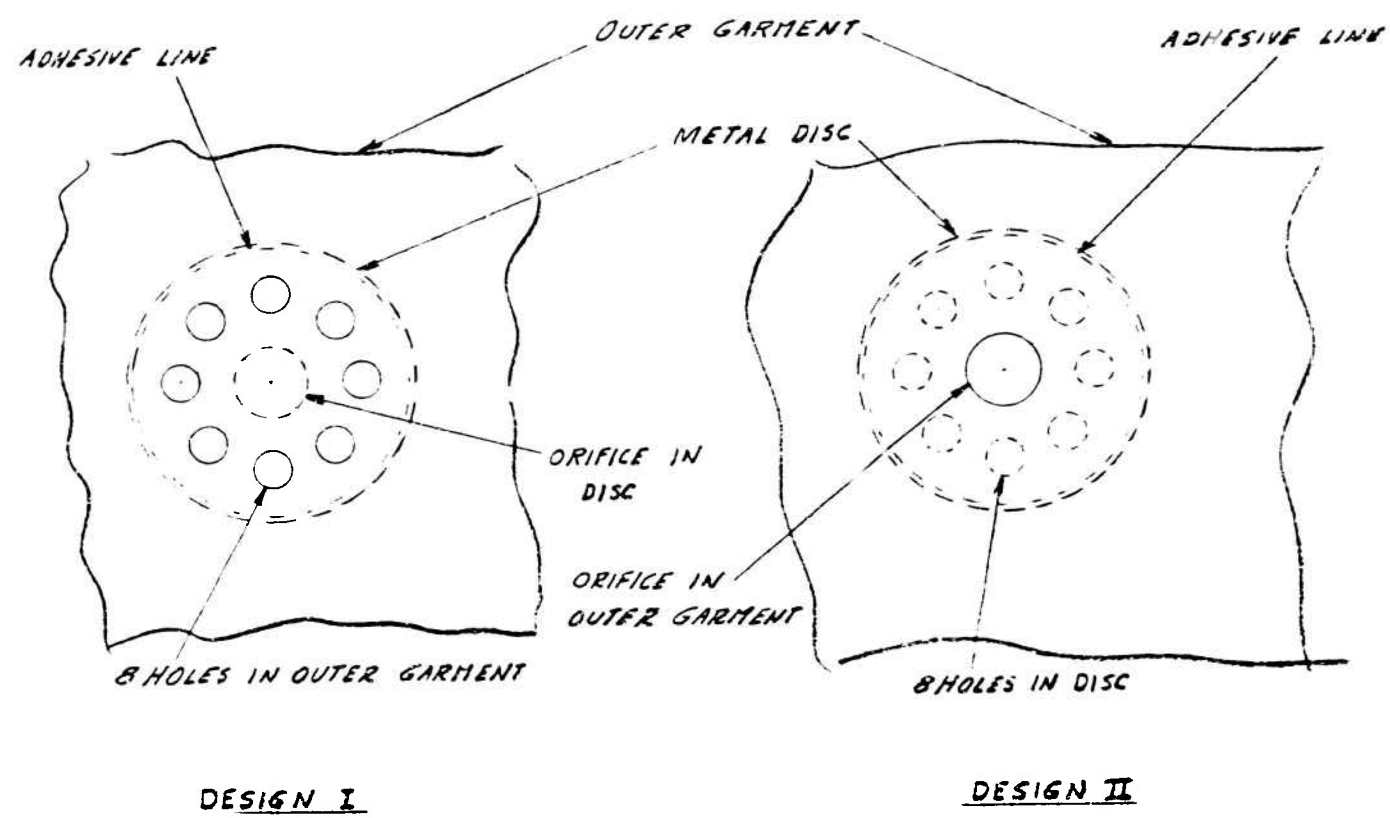


FIGURE 14. Exhaust Valve

AC823
THERMALIBRIUM SUIT
CYCLE 1 4-6-64

With the exception of the barrier material, the suit was made from materials specified by the U. S. Army Natick Laboratories. The outer garment material is the heaviest (14 oz. per square yard) and investigations made to date indicate that this material cannot be reduced in weight without introducing pin holes in the neoprene coating. The spacer material is 8 ounces per square yard and the barrier material 3 ounces per square yard. Minor weight reduction can be accomplished by making the valves out of plastic, using a lighter weight zipper, and possibly doing away with the snap fasteners and polyurethane foam. However, it does not appear possible at this time to reduce the weight of the suit below 7 pounds.

12. Fabrication. Fabrication problems on a production basis are not too difficult on the spacer, barrier, and underwear, but are extensive on the outer garment because of the cemented seams, reverse contours, and the high elasticity of the neoprene nylon knit material. An index system was developed and used on the suits submitted in this cycle and incorporated in the patterns. The edges of the patterns, which are on the top of the seam, are notched along the outer edge, and the mating patterns, which will be on the under side of the seam, are perforated 1/2 inch in from the edge. When the patterns are cut, these indexes are marked on the material. The index marks range from 6 to 8 inches apart on long straight sections to 2 inches apart on reverse contours. This allows the material on both the top and bottom pattern to be stretched evenly, resulting in a seam free from wrinkles.

The sequence of assembly of the outer garment is listed below:

(1) Join D1 - Right-hand front panel to right-hand upper back panel - start at arm pit.

(2) Join D2 - Left-hand front panel to left-hand upper back panel - start at arm pit.

(3) Join B - Right-hand and left-hand upper back panel - start at collar.

(4) Join H1 - Right-hand shoulder seam - start at arm.

(5) Join H2 - Part way only - Left-hand shoulder seam - start at arm.

(6) Join M1 - Right upper and under sleeve pattern.

(7) Apply adhesive to K1 - Do not join - Right upper and under sleeve.

(8) Join M2 - Left upper and under sleeve pattern.

(9) Apply adhesive to K2 - Do not join - Left upper and under sleeve.

(10) Join N1 and O1 - Right-hand sleeve to right side of vest.

(11) Join N2 and O2 - Left sleeve to left side of vest.

(12) Apply adhesive to S and Q - Let dry, do not join - Collar - Neck seal.

(13) Join P - Collar neck seal to collar.

(14) Finish joining H2.

(15) Activate Q and join Q.

(16) Activate S and join S - Neck seal to collar neck seal.

(17) Join R - Neck seal lap.

(18) Activate K1 and join - right sleeve.

(19) Activate K2 and join - left sleeve.

(20) Join F1 - Right back leg and right front leg.

(21) Join F2 - Left front leg and left back leg.

(22) Apply adhesive to G1 and G2 - Do not join, let dry.

(23) Join A2 and J2 - Bottom of left upper back panel to top of left back leg.

(24) Join J1, A1, L1, L2 - Bottom of right upper back panel to top of right leg panel - Left crotch seam to right crotch seam.

(25) Activate G1 and join - right leg.

(26) Activate G2 and join - left leg.

(27) Join C1 and T1 - Bottom of right front panel to top of right front leg.

(28) Join C2 and T2 - Bottom of left front panel to top of left front leg.

(29) Join E.

(30) Assemble zipper.

To prepare the seams for assembly, the seam was first cleaned with benzene, and after drying, a coat of adhesive was applied. After 10 minutes, a second coat was applied and permitted to dry for 5 minutes. The seam was then joined. After joining, the seam was rolled (by a hardwood roller) both from the outside and inside, taking care to assure that the edges of the material were firmly sealed. To activate the adhesive on a dry seam, the adhesive must be wet with benzene applied from a brush. Two to five minutes must be allowed for the seam to become tacky and join.

13. Testing. Testing of the suit by Mine Safety Appliances Company was limited, to back pressure readings with a subject in the suit, because of lack of test equipment. The subject was 5'9-1/2 inches tall and weighed 145 pounds. The maximum flow of air obtainable by MSA was 17.6 CFM at 4 inches of water pressure. This was fed into the suit through the two inlet valves and pressure readings were taken at the extremities.

Location	Pressure Inches H_2O
Left Arm	.4
Right Arm	.4
Left Ankle	.4
Right Ankle	.4
Neck	.5
Exhaust valve opening (one valve only)	.2

While the above tests were not conclusive, based upon Natick Laboratories test procedures, they do indicate that the suits should be within the scope of the design paramet rs.

The above test wa run on one subject only, but several subjects, of larger and smaller bod measurements were used to determine the ease of donning and doffing. The largest weighed 185 pounds and was 5'10 inches in height, and the smallest weighed 130 pounds and was 5'7 inches in height. The suit is not easily donned on the first try, but with practice it becomes much easier.

All subjects commented favorab n the cooling effect of the thermalibrium concept.

14. Material Investigation. Other materials investigated in this program included those listed below:

Alden Rubber Company	-	Acrylonitsile coated nylon
B. F. Goodrich Company	-	Dental Dam 10-mil natural rubber
Reeves Brother Inc.	-	Hypalon coated stretch fabric (DP-58-D-6)
	-	10-Mil polyurethane film
	-	Neoprene-coated stretch fabric (DP-58-C-15)
	-	Neoprene-coated knit (DP-58-C-7)

J. W. Wood Company	-	Lycra 3-way stretch material (#4607)
	-	Lycra 3-way stretch material (#2510)
Archer Rubber Company	-	Neoprene-coated nylon (#9100)
	-	Neoprene-coated nylon (#9085)
	-	Hypalon coated nylon (#18)
Lincoln Fabrics	-	Polyurethane-coated nylon (#9199 PCB)
Sun Chemical Corp.		5-mil polyurethane-coated nylon scrim (FACILFLEX A)
Hartz Mason	-	Polyurethane-coated nylon (#900191)
H. M. Sawyer & Sons	-	Neoprene-coated knit (WS-2842)
Narrow Fabric Company	-	Lycra spandex 2-way stretch (SB-4021W)
Talon Inc.	-	Pressure Seal Zippers

The pressure seal zippers obtained from Talon are a new concept developed in England, and are being developed for production in the United States. This zipper provides a double seal and can be flexed in any direction without breaking the seal. However, the teeth on the zippers tested came loose and jammed the zipper after two or three closures. Talon has indicated that these zippers were some of the first zippers made in their initial run and that this weakness can be overcome. These zippers were reevaluated on cycle II of this contract

C. FURTHER STUDIES

1. The use of commercially purchased underwear if the moisture absorption is not critical.

2. The use of zippers at the wrists and ankles to facilitate donning and doffing of the suit and sealing to the shoes and gloves.

II. CYCLE II

A. INTRODUCTION

The requirements specified for cycle II of this contract called for the production of 34 air distribution garments in accordance with patterns furnished by the U. S. Government and in accordance with the following modifications to the air distribution systems (suits) fabricated under cycle I:

1. The basic configuration and suit size of the distribution system to be the same as previously supplied.

2. A comfort liner to be added to the spacer system and to be fabricated out of the same type and style Lycra material used as stretch panels in the suit previously supplied.

3. Bind all raw edges of the composite spacer systems with strips of stretchable neoprene bonded nylon fabric.

4. Use a continuous Velcro hook and pile closure to attach space layer system to the gas impermeable layer (#5) in lieu of the snap fasteners.

5. Redesign neck seal and large suit collar of gas sealing layer in accordance with patterns furnished by U. S. Army Natick Laboratories.

6. Stitch all seams in the gas sealing layer in lieu of cementing.

7. The main suit closure of the gas sealing layer shall be a gas sealing zipper (Talon) Type #1, Length 48", coating neoprene. This closure shall be installed in the suit by cementing with neoprene cement and the zipper shall extend from top, front of enlarged suit coller, under the crotch, to rear of suit. Closure shall be closed by moving slide fastener from top of suit collar to rear of suit.

8. Sleeves of the gas sealing layer shall be tapered to an opening circumference at the wrists of 12-1/2 inches.

9. The legs of the gas sealing layer shall be tapered to an opening circumference at the ankles of 15-1/2 inches.

10. The contractor shall supply 4 exhalation flapper valves (approximately 1-1/2" diameter) with a plastic base per suit.

B. DISCUSSION OF WORK

The air distribution system consists of an outer, gas impermeable layer and an inner air distribution assembly composed of a composite of spacer material, barrier material, spacer material and a comfort liner (Figure 8.).

The major problems solved in this cycle of work were the pattern modifications required in the outer, inner and outer spacer, and barrier layers, the development of patterns for the comfort layer, the development of the fabrication techniques required to assemble the air distribution systems, and preparing material specifications and requirements. (Appendices A and B).

1. Outer Layer. The outer or gas impermeable layer provides CBR agent protection, prevents air loss and provides protection for the air distribution system. This layer was fabricated from 0.01 (+0.002 -0.000) x 50 inches 2/70 nylon laminated with neoprene white rubber 14 oz./yard.

The patterns, as used in Cycle I, had to be modified to incorporate the changes specified for this cycle. The major changes were in the neck seal, large collar and closure (these patterns were furnished by Natick Laboratories) while minor changes had to be made in all the patterns because this layer was stitched instead of cemented.

The outer layer was assembled in the following manner:

a. The material was cut 17 layers high using a Maimim cutter with a serrated blade.

b. Velcro hook was attached to each sleeve and leg component using stitch type 301.

c. Velcro hook and pile was attached to the neck seal using stitch type 301.

d. The components of the outer layer were stitched together using stitch type 301, seam type LSq-2.

e. Velcro hook was attached to the neck opening and to each side of the closure using stitch type 301.

f. The gas sealing zipper was cemented to the outer layer using Bostik Adhesive No. 1050.

2. Outer Spacer. The outer spacer provides air passages for the distributing air. This layer was fabricated from Trilock Base Material Spacer Fabric Style 6028.

The patterns, as used in Cycle I, had to be modified to conform to the changes made in the outer layer.

The outer spacer was assembled in the following manner:

a. The material was cut 12 layers high, using a circular cutter on all straight or nearly straight sides and a Maimim cutter with a serrated blade on all curved surfaces.

b. All raw edges were adhesive-dipped, using industrial rubber cement Grade 1177, to prevent raveling.

c. All seams were assembled using a 3-inch wide strip of Lycra with a 3/8 inch seam on each side. The Lycra was attached with a zigzag stitch type 301, seam type SSa-1 (Figure 8).

d. All exposed edges were covered with strips of outer layer material 1-1/2 inches wide, using zigzag stitch type 301, seam type BSa-1.

3. Barrier Layer. The barrier prevents intermixing of inlet and outlet air and also directs the distributing air to the extremities. This layer was fabricated from double-coated polyurethane nylon twill.

The barrier patterns, as used in Cycle I, had to be modified to conform to the changes made in the outer spacer.

The barrier was fabricated in the following manner:

a. The material was cut 17 layers high using a Maimim cutter with a serrated blade.

b. All seams were assembled using 3-inch wide strips of outer layer material. The outer layer material was attached with stitch type 301, seam type LSq-2.

c. Additional pieces of outer layer material were attached to cutouts at the elbows, knees and under the arms, using stitch type 301, seam type LSq-2.

4. Inner Spacer. The inner spacer provides air passages for the distributing air. This layer was fabricated from Trilock Base Material Spacer Fabric Style 6028.

The patterns, as used in Cycle I, had to be modified to conform to the changes made in the outer spacer.

The inner spacer was assembled in the following manner:

a. The material was cut 12 layers high, using a circular cutter on all straight or nearly straight sides and a Maimim cutter with a serrated blade on all curved surfaces.

b. All raw edges were adhesive-dipped, using industrial rubber cement Grade 1177, to prevent raveling.

c. All seams were assembled using a 3-inch wide strip of Lycra with a 3/8 inch seam on each side. The Lycra was attached with a zigzag stitch type 301, seam type SSa-1 (See Figure 8).

d. All exposed edges were covered with strips of outer layer material 1-1/4 inches wide, using zigzag stitch type 301, seam type BSa-1.

5. Comfort Layer. The comfort layer provides a form-fitted inner liner to ease donning and doffing of the air distribution suits. This layer was fabricated from Lycra Style #4608.

The patterns for this layer had to be developed to conform to the outer layer. The comfort layer was not used in Cycle I.

The comfort layer was assembled in the following manner:

a. The material was cut 12 layers high, using a Maimim cutter with a serrated blade.

b. This layer was assembled using stitch type 505, seam type SSa-1.

6. Composite Spacer System. The composite spacer system distributes the air from the inlet ports through the inner spacer to the extremities around the barrier and back through the outer spacer to the outlet ports. The spacer system is composed of the outer spacer, barrier, inner spacer and comfort layers in that order, with the comfort layer next to the body.

The composite spacer system was assembled in the following manner:

a. The layers were placed one inside the other. (Care had to be taken to assure proper alignment of the sleeves and legs.)

b. All exposed edges of the spacer system were bound with 2-1/4 inch wide strips of outer layer material, using a zigzag stitch type 301, seam type BSa-1.

c. Velcro pile was attached to the sleeves, legs, neck and to each side of the front opening, using stitch type 301, seam type SSAA-1.

d. Excess outer layer material was trimmed to within 1/8 inch of the Velcro pile.

7. Air Distribution System. The air distribution system provides protection from all possible environmental conditions.

The air distribution system was assembled in the following manner:

a. The composite spacer system was attached to the outer layer by means of the Velcro. (Care had to be taken to assure proper alignment of the legs and sleeves.)

b. The neck seal was closed by means of the Velcro.

c. The zipper was closed.

C. FURTHER STUDIES

The following changes should be studied in the fabrication of the air distribution system:

1. An improved method to prevent raveling of the spacer material should be developed. The adhesive dipping is time-consuming, the drying time excessive, and the adhesive causes the thread to ravel when the Lycra is attached to the spacer material.

2. An additional strip of outer spacer material added to each side of the main clousre to minimize stretching and wear when the zipper is opened and closed.

3. The zipper stitched in addition to cementing to the outer layer.

These changes would ease the fabrication of the air distribution systems.

D. CONCLUSIONS

The air distribution systems can be fabricated using standard production equipment and techniques.

APPENDICES

APPENDIX A

MATERIAL SPECIFICATIONS

0.010 (+0.002 -0.000) x 50" 2/70 Nylon (HC-1 color natural, laminated with neoprene base white rubber 14 oz./yd. Style #5132
Rhee Industries, Rohm and Haas Company, Warren, Rhode Island

Trilock Base Material Spacer Fabric - 45" wide. Style 6028
U. S. Rubber Company, Textile Division, New York, New York

Lycra Style #4608. Nylon Warp color white 60" wide
J. W. Division, Kendall Company, Stoughton, Massachusetts

Double-Coated Polyurethane O.D. Color on 1.3 oz. Nylon Twill TDA 3780 N - 160 - 40" wide.
Hodgeman Rubber Company, Framingham, Massachusetts

Style #1430 Medium Duty Chain closed both ends 2-1/16" wide x 48" long Zipper, Pull Tab on Rubber Side
B. F. Goodrich Aviation Products, Akron, Ohio

Thread (Polyester Fiber L.T. Size E 69 Color Natural Class I) Size E69 Natural Dacron (Polyester) Thread.
Premier Thread Company, Bristol, Rhode Island

Rubber Cement - Grade 1177
Industrial Rubber Products, Pittsburgh, Pennsylvania

Bastik Adhesive No. 1050
B. B. Chemical Division, United Shore Machinery Corp., Middleton, Mass.

Velcro Pile, Industrial Type 80 - 3/4" wide. Color Black
Velcro Corporation, 681 Fifth Avenue, New York, New York 10022

Velcro Hook, Industrial Type 80 - 3/4" wide. Color Black
Velcro Corporation, 681 Fifth Avenue, New York, New York 10022

APPENDIX B

BILL OF MATERIAL

Material	Outer Layer	Outer Spacer	Barrier	Inner Spacer	Comfort Layer
Neoprene-Coated Nylon Knit	3.4 yds.	0.3 yds.	0.5 yds.	0.3 yds.	
Trilock		3.4 yds.		3.4 yds.	
Double-Coated Polyurethane			3.4 yds.		
Lycra		0.3 yds.		0.3 yds.	2.3 yds.
Zipper					1 each
Rubber Cement		3.7 oz.		3.7 oz.	
Bostik Adhesive	1 oz.				
Velcro Pile	6 in.		107 in.		
Velcro Hook	113 in.				
Polyester Thread			8 oz.		

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13. ABSTRACT

The results of material optimization, fabrication techniques and the fabrication of prototype air distribution systems for thermalibrium clothing are summarized. The engineering research effort was accomplished in two work phases. The initial phase was directed to the testing of materials, the development of fabrication techniques and the fabrication of two prototype systems for design verification testing at U. S. Army Natick Laboratories. The second phase of the program involved the modification of patterns, and the fabrication of 34 air distribution systems on a modified production basis. The counter-flow system of distribution ventilating and/or conditioned air for protective clothing can be manufactured under standard production methods, using commercially available materials.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Research	8					
Design	8					
Fabrication	8					
Testing	8		8			
Air circulating	8,9		4		8,9	
Systems	8,9		4		8,9	
Valves	8,9				8,9	
Protective clothing	4		4		4	
Armed Forces equipment	4		4		4	
Fabrics			9			
Materials			9			
Carrier			0			
Spacer			0			
Mass production					8	
Methods					8	